

MINERALOGICAL AND OXYGEN ISOTOPIC CONSTRAINTS ON THE FORMATION OF CHAINPUR (LL3) AND PARNALLEE (LL3) CHONDRULES. J. C. Bridges¹, I. A. Franchi², R. Hutchison¹, A. S. Sexton² and C. T. Pillinger², ¹Department of Mineralogy, Natural History Museum, Cromwell Road, London, SW7 5BD UK. (J.Bridges@nhm.ac.uk), ²Planetary Sciences Research Institute, Open University, Walton Hall, Milton Keynes, MK7 6AA UK.

INTRODUCTION

We report initial results of a mineralogical and oxygen isotopic study of a set of chondrules physically separated from Chainpur (LL3) and Parnallee (LL3). By combining chondrule size, bulk major element compositions, mineral compositions and bulk oxygen isotopic compositions, we aim to provide some constraints on the isotopic exchange and chemical fractionation processes involved in chondrule formation.

TECHNIQUES

Twenty five randomly selected chondrules were separated from Chainpur (Natural History Museum no. BM1915, 86) by gentle crushing and use of a scalpel. Each chondrule was split. Where possible, aliquots were set aside for oxygen isotope analysis and the remaining material was made into polished blocks. Fifteen chondrules were separated from Parnallee in a similar way (Natural History Museum sample no. BM34792). Samples were analysed using EDS and WDS. Bulk compositions of the chondrules were determined using a Cameca SX50 WDS system on a grid pattern of at least 80 focused spots with a 50µm spacing. Oxygen isotopic analyses were made on 0.1-1.62mg fragments of some chondrules using a method outlined previously [1].

RESULTS

Mineralogy: Of the 40 chondrules, 12 are porphyritic olivine-pyroxene (pop), 9 radiating pyroxene (rp), 6 porphyritic pyroxene (pp) and 5 barred olivine (bo), with the remainder being other textural types. One chondrule contains both bo and pp areas. The proportions of textural types in both meteorites are similar to those observed in a survey of chondrules from ordinary chondrites [2]. Parnallee appears to have a higher proportion of larger chondrules than Chainpur, with size ranges of 1.5-7mm and 1-5mm respectively.

The olivine (Fo₇₁₋₉₅ in Parnallee, Fo₅₅₋₉₂ in Chainpur) and low-Ca pyroxene (En₆₆₋₉₆ in Parnallee, En₄₄₋₉₃ in Chainpur) compositions are typical of UOCs. Thirteen of the total 40 chondrules contain some plagioclase of An₇₅ or greater.

Chondrule compositions: Correlation coefficients were calculated between the major elements using those Chainpur and Parnallee chondrules (36) for which bulk compositions were available. The chondrules are considered together because no matter which chondrule classifications were used *e.g.* porphyritic, non-porphyritic *etc.* the same element groupings are evident.

Correlations significant at the 0.95 level of certainty were used. The clearest group is Ca, Al, Ti and Mg. Another two groups are Fe, Mn and Si, K, (Na), Mn, Cr. The lack of a significant correlation between Fe and Ni reflects the metal-depleted mineral assemblages within most chondrules. There is no simple, direct mineralogical control on these element groupings. Mg and Al are not,

for instance, concentrated together in any common constituent of chondrules.

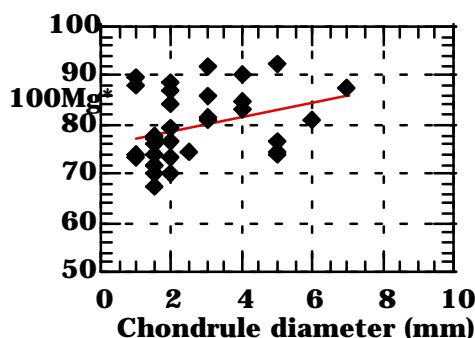


Fig. 1. 100Mg/(Mg+Fe_(tot.)) atomic ratio vs. chondrule diameter. Best fit line $y=76+1.4x$ ($r=0.32$).

There appears to be a weak correlation between the Mg/(Mg+Fe_(tot.)) atomic ratios of the whole chondrules and their diameters (Fig. 1). This is a reflection of the generally higher Fe_(tot.) contents in the smaller chondrules. This correlation does not appear to be present in the largest macrochondrules.

Oxygen isotopes: The oxygen isotopic compositions of the Chainpur chondrules are typical of those from OCs (Fig. 2). Taken together, the chondrules lie on a regression line of slope 0.88. There is no clear link between the mineralogy of the chondrules and their oxygen isotopic compositions. For instance two chondrules consisting mainly of pyroxene, with lesser amounts of mesostasis, lie at opposite ends of the field of isotopic compositions. The different textural types scatter throughout the field. Similarly, the mineral compositional parameters do not correlate with isotopic composition. The chondrule diameters (noted beside the points on Fig. 2) do, however, suggest there may be a link between isotopic composition and chondrule size. The largest four (3-5mm diameter) of this set of chondrules fall at the lighter, ¹⁶O-rich end of the field.

DISCUSSION

The Chainpur chondrules' mixing line on Fig. 2 deviates from the mixing line of slope 0.77 (CRIL) defined for a broad range of chondrules and clasts in OCs [3, 4]. This indicates that the line of slope 0.77 represents an average mixing line. There may have been multiple oxygen isotopic reservoirs, at and near, extensions at either end of the CRIL mixing line.

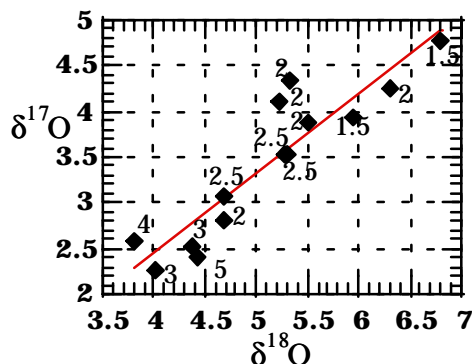


Fig. 2. Oxygen isotopic compositions and chondrule diameters (mm). Best fit line $y = -1.1 + 0.88x$ ($r = 0.92$).

There is evidence that framework minerals - such as silica polymorphs or feldspar - in chondrules and clasts facilitate gas/solid exchange [3]. However, this effect is probably only noticeable where the proportion of such minerals is high (e.g. >30 vol.%). This can explain the apparent lack of mineralogical control on the oxygen isotopic compositions of the Chainpur chondrules. A model involving gas-solid oxygen isotopic exchange is still favoured over one in which gas-liquid exchange is the dominant mechanism [5]. This is because the highest degree of isotopic exchange between a gas and a liquid might be expected to occur in those chondrules (barred olivine) which were held longest at above-liquidus temperatures. There is no evidence for such an effect either in the limited amount of data presented here or in other work.

The smaller Chainpur chondrules - which have the more ^{16}O -poor compositions - may have exchanged to a high degree with an ^{16}O -poor gas compared to the larger chondrules. Such a high degree of exchange would be facilitated by the high surface area/volume ratio of smaller chondrules. This data is, however, in contrast to that obtained from the H-chondrites Dhajala (H3.8) and Weston (H4), where chondrules <290 μm in diameter were considered to have more ^{16}O -rich compositions [4]. One possible explanation for this is the presence of isolated ^{16}O -rich olivine grains in chondrites [6]. Another possibility is that chondrules from H-chondrites - unlike those from LL-chondrites - exchanged with an ^{16}O -rich rather than ^{16}O -poor gas reservoir.

The chemical groupings within the chondrule bulk compositions are similar to those identified by other workers [7]. The grouping of refractory lithophiles (Ca-Al-Ti-Mg in this work) is difficult to interpret. Models in which the compositional groups were regarded as nebular condensates have largely been superseded [8]. The condensate model requires that chondrules formed in a closed system without, for instance, exchange of volatiles with the surrounding medium. This in turn requires that chondrules formed at <1000°C - a temperature that is now generally regarded as too low.

An alternative explanation has been proposed by Dodd [9] and Alexander [10], who demonstrated that some trends of bulk chondrule compositions - similar to those listed above - could be formed through random picking of the major chondrule phases (*i.e.* olivine, low-Ca pyroxene, high-Ca pyroxene, glass, metal). This recycling model, implies that pre-existing chondrules or rocks/regolith were the major constituent of later-formed chondrules. Furthermore, it has been suggested that the positive correlation between Mg and Al could be explained by evaporative loss of Fe during chondrule formation [11]. The tentative link between Chainpur chondrule sizes and their $\text{Mg}/(\text{Mg}+\text{Fe}_{\text{tot}})$ ratios provides some support for a link between chondrule size and Fe gain/loss effects. This correlation may not be present in the largest, macrochondrules (e.g. $\geq 1\text{cm}$ diameter).

CONCLUSIONS

An important control on both the oxygen isotopic compositions and bulk chemical compositions of LL3 chondrules appears to be their size. These tentative conclusions need to be tested by the gathering of more data but smaller chondrules in LL-chondrites (e.g. approximately <2mm diameter) seem to have more ^{16}O -poor compositions than larger chondrules. Smaller chondrules studied here may also have experienced more Fe-gain, leading to lower bulk $\text{Mg}/(\text{Mg}+\text{Fe}_{\text{tot}})$ atomic ratios. This supports models for chondrule formation which involve both the recycling and remelting of chondritic material within an open system, with varying degrees of elemental exchange (e.g. O, Fe, alkalis) with surrounding media.

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